Abstract — when cold rolling stainless steel wide strips, some flatness defects can occur. A flat strip means that when lying on a flat horizontal surface the strip touches the surface at every point. Flatness defects cause shifting, strip breakage, and axial forces. The direct consequences are a loss of material, a waste of time, and a lot of damage or premature wear of the equipment. Sort edge (or long center), long edge (or short center), quarter buckles, randomly located overrolled areas are considerate flatness defects. To correct these defects besides automatic flatness control, which is very expensive, one may use a stretcher leveler.

Keywords — cold rolling, flatness defects, shape defects, stainless steel, wide strips

I. INTRODUCTION

In the last years, the stainless steel industry achieved remarkable growth rates. At the same time, its consolidation is going on and the steel markets become more and more global. In such a business environment it is very important for stainless steel producers to meet highest quality requirements and at the same time to lower the production costs by increasing quality of products and diminish non-conform products.

In this article we will try to explain how to avoid flatness defects during cold rolling of stainless steel wide strips.

II. RESEARCH AND RESULTS

A flat strip, by definition, means that a strip lying on a flat surface touches at every point (even if the wide strip is further longitudinal slitted in a slitting line. A flat strip is shown in figure no 1.

Fig. 1. Flat strips

a) The short edges (long center) defect shows so called “pockets” located in the center of the strip. This is caused due to the phenomenon that the center has undergone a heavier reduction than the edges of the wide strip. After longitudinal slitting the length of each slit strand, from each edge of the initial strip to its center, is progressively greater. The slit strands are fanshaped (each one has one edge longer than the other one). If the number of slits is uneven, the only straight strand is the center one, as shown in figure 2.

Fig. 2. Fanshaped slit strands

The pockets (or center buckles) depend of the thickness of the strip and accordingly of the hardening of the rolled material. For a thick (over 1 mm) and hardened material, the “pockets” are long and wide. For thinner gauges (0.15-1 mm) and not so hardened material, the buckles are transverse with a close pitch and an angle. This kind of pattern is called “hearing bone” (fig 3) and can occur when rolling with small diameter working rolls.
For even thin material (under 0.15 mm), only small buckles can occur because of low rigidity of the material. Usually the strip looks like hammered copper (small “pockets”) as presented in figure 4.

Correction of the defect:
First case: The short edge defect is a progressive increase in thickness from the center to the edge of the strip (figure 5).

First case is presented in figure 8.

Material is progressive decreasing in thickness from the center to the edge (crown) The best remedy is to correct the gap by means of the crown adjustment or roll bending. Lacking these means, the mill operator can correct the problem with the intermediate rolls by reducing the effective flat.

Second case is presented in figure 9.

The defect occurs only in the nearby of the strip edges, material is decreasing in thickness from center to edges. The counter measurement is to reduce the effective flat.

c) Over rolled areas symmetrically distributed is shown in figure 10.

Usual name for this defect is “quarter buckle”. The distance “x” is approximate equal to 25% of the strip width. The defect occurs when the taper of 1st intermediates rolls is too small. The fact is that if the taper is too low (reduction on pass is too high for a given taper) we try to reduce effective flat in order to avoid edge waviness. The overlap (taper on strip) becomes too high resulting over rolling at the points where the tapers start.

d) Over rolled areas located randomly are shown in figure 11.

For this kind of defect there are known multiple causes:
Oil lubrication un-uniform distributed on the width of the strip
Damaged work rolls
Profile of the hot rolled strip (it is very important to know that all the coils from the same batch will present this defect)

Differences in surface finish of the strip (under or over pickled) resulting a friction coefficient different from different areas of the strip.

First case refers to the shape of hot rolled material which is not good. The pattern is as shown in figure 12. Two localized over thicknesses (1% is enough) create an over rolling condition, even during the final pass. The cause certainly comes from narrow strips that have been rolled at first on the hot rolling mill. Usually the widest material should be rolled first.

![Fig 12. Over thicknesses of rolled material](image)

Second case is “quarter buckle” which is caused by the material stuck on an intermediate roll. If some particle of material adhere to the intermediate roll this particle will scratch the work roll. The diameters of working and intermediate rolls being different the scratch will never be in the same location and so a groove is created on the work roll (figure 13; 14).

![Fig 13. Quarter buckle during milling](image)

![Fig 14. Quarter buckle during unwinding](image)

In the case of thick gauges, only the strip’s appearance is affected. But, in the case of thin gauges (below 0.3 mm), there are many rounds on the coiler, and the strip is not stiff.

For a thickness of 0.2 mm, and a coiler diameter of 610 mm, if the coil diameter is 1500 mm on the coiler, the number of rounds on the coiler is (theoretically):

\[(1500-610) / 2 \times 0.2 = 2225\]

The very localized increase in diameter on the coiler is:

\[2225 \times 0.004 = 8.9 \text{ mm}\]

The consequence is a defect in shape (very narrow). This defect is easy to recognize: On the coiler, the bigger the coil, the greater the defect. If the work rolls are changed, the new work rolls will produce the same defect, maybe on the first coil itself, the defect being located exactly at the same place. The sole solution is to change the intermediate rolls. (Note: After a serious rolling incident, the intermediate rolls should always be checked.) When rolling thin gauges, the operator should occasionally inspect the winder visually. The top generating line of the strip should be flat (figure 15).

![Fig. 15. Strip top generating line](image)

Third case is represented by so called “snakes”. If a thin gauge is wound under excessive tension, longitudinal waves are created between the deflector roll and the coiler, the winding is not flat, and one or more peripheral bumps (narrow) are created. The defect appears immediately after starting. The strip has to be cut and started again under lower tension (figure 16).

![Fig. 16. Snakes](image)

Strip profile during rolling:

Evolution of the strip profile is influenced by two very important parameters:

1) The temperature inside mill housing. Rolling generates heat. The oil flow removes the heat, and a balanced temperature is reached. This equilibrium depends on the rolling conditions, particularly on the speed and the reduction size. The work rolls heat up quickly — faster than the intermediate rolls and back-up rolls. In the short time period between two passes, cooling is negligible. The time period between two coils is a little longer, but not enough to create a great difference of temperature. However, the housing has thermal inertia and, after a long break (over a weekend, for example), when the mill has become cold, several strips must be rolled before the mill gets warm again. Thus, the temperature of the mill is always in flux. This would have no affect on flatness if the changes were equal across the face of the rolls. However, while the heat generated by deformation of
the strip is restricted to the width of the strip, the oil flow is distributed along the entire face of the work rolls, the spray nozzle banks being usually wider than the strip. Moreover, heat loss is higher on the ends of the rolls. Consequently, the extremities of all the rolls are colder than the middles. The real temperature profile of the rolls and the amount of thermal expansion along them is a very complex issue. However, the most common and important observation is that this situation creates a crown on the rolls — i.e., a convex form known as the thermal crown. To understand the influence of temperature, let us do a simple thermal expansion calculation. The thermal expansion of steel is roughly 1 mm per meter per temperature rise of 100°C. Thus, for a roll diameter of 200 mm, a difference of temperature of only 10°C between the center and ends results in a crown of 0.02 mm.

2) Rolling speed: Any change in rolling speed produces an important change in rolling conditions. During acceleration,
- roll flattening is reduced. Roll flattening can be compared to the flattening of tires on the road: if the car is stopped, the flattening is maximum, and it is very difficult to turn the wheel; at low speed, it becomes easier; at high speed, it is very easy. The contact arc becomes smaller and smaller as the speed increases. Consequently, the reduction is easier.
- lubrication is better: the oil is more effectively drawn between the rolls and the strip. The wedge of oil at the entry of the contact arc is longer.
- the coefficient of friction decreases. Its rate of change is not linear; it is faster at the beginning of the acceleration. At speeds in excess of 120 m/min, the rate of change is low. For these three reasons, rolling becomes easier and easier as the mill speeds up. However, during acceleration, the Roll Separating Force (R.S.F.) also changes — it decreases. In order to get the same exit thickness as the speed increases, the operator, or the Automatic Gauge Control, has to correct the gap — only to find that the separating force decreases again.

During deceleration, the edges of the strip become wavy (reverse change). The effects of acceleration are emphasized by any differences in strip temperature (the ends of the strip, being rolled at lower speeds, are colder and therefore harder) and by the thickness of the ends. The stainless steels, series 300 (austenitic), are particularly sensitive to rolling temperature. The presence of rolling problems on the ends of the strip can be a reason to increase the number of passes.

How can one control shape on strip ends?
- roll bending, or shifting of the tapered rolls plus crown adjustment, should not reach their limit and should be ready to react when deceleration is ordered.
- If front and back tensions are increased during deceleration — up to 20% if necessary — the R.S.F. will increase less than it would without that increase in tension. High tension is also used at the beginning of the next pass, and reduced during acceleration to its normal value.
- The coolant flow can be used to equalize temperatures in some mills, but this will depend on the rolling speed.

Generally, the minimum temperature will be about 30% of the maximum. But the rolling speed must change — for example, from 20 to 600 m/min. So, the use of coolant to control temperature is not very reliable.
- If the operator does not correct the thickness on the ends of the strip, the R.S.F. will not change very much.

In the case of A.G.C., the operator can switch it OFF while rolling the extremities. But the extremities that fall outside tolerance limits are longer. If process automation is provided, the problem is different.

3) Thickness deviation on entry side

Often a few meters of the ends of the coil are thicker. This occurs mainly on stiff materials (where cold extremities are created during hot rolling). The few meters become longer and longer from pass to pass as the strip is reduced in thickness. It is not possible to correct these thickness differences so that the problem disappears from the very first pass, because even if the thicker portions are corrected at the first pass, they remain harder than the rest of the coil and still require higher separating force at every subsequent pass. This effect is compounded by the other ones (speed, for example) — during acceleration, mainly at the beginning, the separating force decreases very much. It increases the same amount during deceleration. The best guide for the mill operator is the separating force indicator, which will tell him the amount of the adjustment to make. Another way to reduce the size of the adjustments is to start the strip with wavy edges (slightly wavy). The waviness will get smaller and disappear when the mill gets up to speed. Remember again the sensitivity of thin gauges, particularly for hard materials. Very good operator skill is required.

III. CONCLUSIONS

Perfect shape is and will always be a very difficult problem. Besides automatic flatness control, which is very expensive, one may use a stretcher leveler.

After cutting to length, sheets are, one by one, stretched (for example, 2% of elongation). After that, the two extremities and the two edges are cut. The result is perfect, but it is expensive. For strip, a special leveler with a minimum of three rolls (figure 17) is provided on the skinpass mill, between the mill stand and the exit deflector roll. It can correct all light defects (there is some elongation). The leveler is idle, and high tension is necessary to pull the strip through the leveler. Consequently, bridle rolls are necessary for thin gauges (below 0.7 mm approximately) (figure 18).
The strip tension is low between the mill stand and the leveler (the leveler absorbs most of the tension). This leveling operation can also be carried out on separate equipment. The operation can also be performed on hard materials, for the leveler has many rolls.

REFERENCES